We are IntechOpen, the world's leading publisher of Open Access books Built by scientists, for scientists

4,800
Open access books available

122,000
International authors and editors

135M
Downloads

Our authors are among the

154
Countries delivered to

TOP 1%
most cited scientists

12.2%
Contributors from top 500 universities

BOOK CITATION INDEX
CLARIVATE ANALYTICS
INDEXED

WEB OF SCIENCE™

Selection of our books indexed in the Book Citation Index
in Web of Science™ Core Collection (BKCI)

Interested in publishing with us?
Contact book.department@intechopen.com

Numbers displayed above are based on latest data collected.
For more information visit www.intechopen.com

Urban Development with the Constraint of Water Resources: A Case Study of Gansu Section of Western Longhai-Lanxin Economic Zone

Gao Xiang

Abstract

Water is the essential resource for urban development of Gansu section of West Longhai-Lanxin economic zone, which is not only the "Golden Development Line" of Gansu province but also the significant component of the new Silk Road within China. Based on more than 2000 data points reflecting various meaningful aspects of urban systems and water resource systems, and using a quantitative measurement model and ArcGIS, this study aimed at discussing the temporal-spatial variations of water resources constraint on urbanization in the Gansu section. From 1989 to 2007, the water resources constraint intensities (WRCIs) of Gansu section and its nine cities have been generally decreasing, albeit with much fluctuation, and the decrease has been more rapid since 2000, with Lanzhou and Jinchang as the most representative cities. From the perspective of water resource constraint on urbanization, the research on urbanization process of Gansu section is not only necessary for the shaping of an independent theoretical system on relationship between water resource and urbanization, but also has very crucial practical significance for promoting construction of resource-saving and environment-friendly cities in Gansu section, arid and semi-arid areas as well as for promoting harmonious regional development.

Keywords: Gansu section of West Longhai-Lanxin economic zone, silk road, water resource constraint, urbanization, temporal–spatial variation

1. Introduction

Water is the strategic resource and basic material for human being's survival and for the economic and social development. Biswas has made special researches on the world development model, including the city, and holds opinions that overall developing trend of urban economic activities around the world will face the rigid constraints of increasing resource

shortage in the twenty-first century, including the constraint of water resource [1]. Mcmichael also points out that urbanization will threaten human being's living environment and health in an important way. The urban expansion, industrial growth and population growth will bring large pressures on local water resources and ecological environment [2]. On World Water Day in 2002, Koichiro Matsuura, the Director-General of UNESCO, remarked that "the impending water resource crisis poses one of the most serious challenge to the current world". Changming investigated and believed that water consumption over the whole world in the nineteenth century increased by 8 times, among which agricultural water increased by 7 times, industrial water by 20 times, urban domestic water by 12 times, and the water consumption quantity doubled every 15 years [3]. And in the twentieth century, world population grew by two times, while the human water consumption still increased by five times on condition that some developed countries had already realized zero growth of water demand. It is predicted that in 2050, urban water use will be equal to the current global water consumption and over 55% population around the world will face the problem of water crisis [4]. Water security problem in the twenty-first century not only directly threatens human being's food security, economic security, and ecological security, but also endangers social security and national security, and even people's living security, especially in arid and semi-arid areas.

This situation brings increasingly difficult choices to China, which is facing water shortage, overall eco-environment deterioration, and the significantly accelerating urbanization. Nobel economics laureate Stiglitz (2000) pointed out that "China's urbanization is a global event with the most profound influence in the twenty-first century other than high-technology". Since 1998, the urbanization level of China has been growing with a rate of 1.5–2.2% points each year. Until the end of 2016, the urbanization rate has reached 57.35%, being the fast urbanization period. The large-scale and fast urbanization in China will highlight the imbalance of water supply and demand, which has become a bottleneck restraining the urban development of our country [5]. Especially in arid and semi-arid areas in northwestern parts such as the Gansu section of western Longhai-Lanxin economic zone, water resource is not only an endogenous variable for urbanization and the social and economic development, but also has an important exogenetic force. In the process of industrialization and urbanization, cities with a fragile eco-environment as the developing background have suffered multi-layers of threats posed by water resources and surrounding eco-environment. However, urbanization is the main approach for these regions to realize modernization, and their urbanization level still has large climbing space compared with that of eastern coastal areas. Therefore, it is especially important and extremely urgent to well coordinate the relationship between urbanization and water resource in these regions. Research on urbanization process of Gansu section from the perspective of water system constraint is not only necessary for the shaping of an independent theoretical system on relationship between water resource and urbanization, but also has very crucial practical significance for promoting construction of resource-saving and environment-friendly cities in Gansu section, arid and semi-arid areas as well as for promoting harmonious regional development.

2. Study area

Western Longhai-Lanxin economic zone starts from Tongguan, Shaanxi province in the east to Urumqi, Xinjiang Province in the west, with the western part of Longhai Railway, the Lanxin Railway, and the high-level roads and communication lines of the same direction as its axis, the provincial capitals and prefecture cities expanding like beads as its nodes, and the vast surrounding rural areas as hinterlands. As a result, an economic region within the scope of 100–150 km in width and over 2700 km in span is formed [6]. On principle of "line links points, points link areas", relying on this trunk transportation line to develop node cities is one of the keys for develop-the-west strategy and also a significant component of the new Silk Road within China.

The Gansu section of western Longhai-Lanxin economic zone (hereinafter referred to as "Gansu section") is an important component of this economic zone, which spans 1542 km and accounts for 57.1% of the zone. *Development Plan on Gansu Section of Western Longhai-Lanxin Economic Zone (2003)* issued by Gansu provincial government shows that Gansu section is composed of nine cities (Tianshui, Lanzhou, Dingxi, Baiyin, Wuwei, Jinchang, Zhangye, Jiuquan and Jiayuguan) as core districts and the non-city influenced districts which are featured with rapid urbanization, high-level openness, strong economy and great developing potential, that are, 42 districts. Directly influenced districts are Pingliang city, Linxia prefecture, Li county, Xihe, Cheng county, Hui county and Liangdang county; indirectly influenced districts are Qingyang city, Gannan prefecture and Dangchang, Wudu, Kang county and Wen county (**Figure 1**).

Gansu section is located at convergence zone of Loess Plateau, Qinghai-Tibet Plateau, and Mongolian Plateau. It is a mountainous plateau landform with complex terrains on which mountain ranges crisscross and various landforms such as high mountain, basin, plain, desert and Gobi deserts with greatly differing altitudes, mainly composed of Hexi Corridor, Qilian Mountains, regions north of Hexi Corridor, Longzhong loess plateau and Longdong loess plateau. Gansu section contains six climatic regions featuring semi-arid climate while the continental climate and drought degree increase from both sides to center areas, making Hexi Corridor become a section with the least precipitation and the most obvious continental climate within this district. Corresponding to drought climate, most districts of Gansu section are with sparse river-network, small runoff, and water resources shortage.

Gansu section is the axial region for economic development of Gansu province. Up to the end of 2015, population in Gansu section reaches 16.359 million, covering 62.93% of total provincial population and concentrating 74.27% of non-agriculture population of the whole province; 2015-year-end agricultural area is 2166,484 ha, covering 66.0% of the province; regional GDP is RMB 514.004 billion, covering 75.70% of the province and concentrating 80.3% of total provincial industrial output value, 84.1% of total construction output value and 83.07% of total wholesale and retail output value. Gansu section is the "Golden Line" in development of Gansu province.
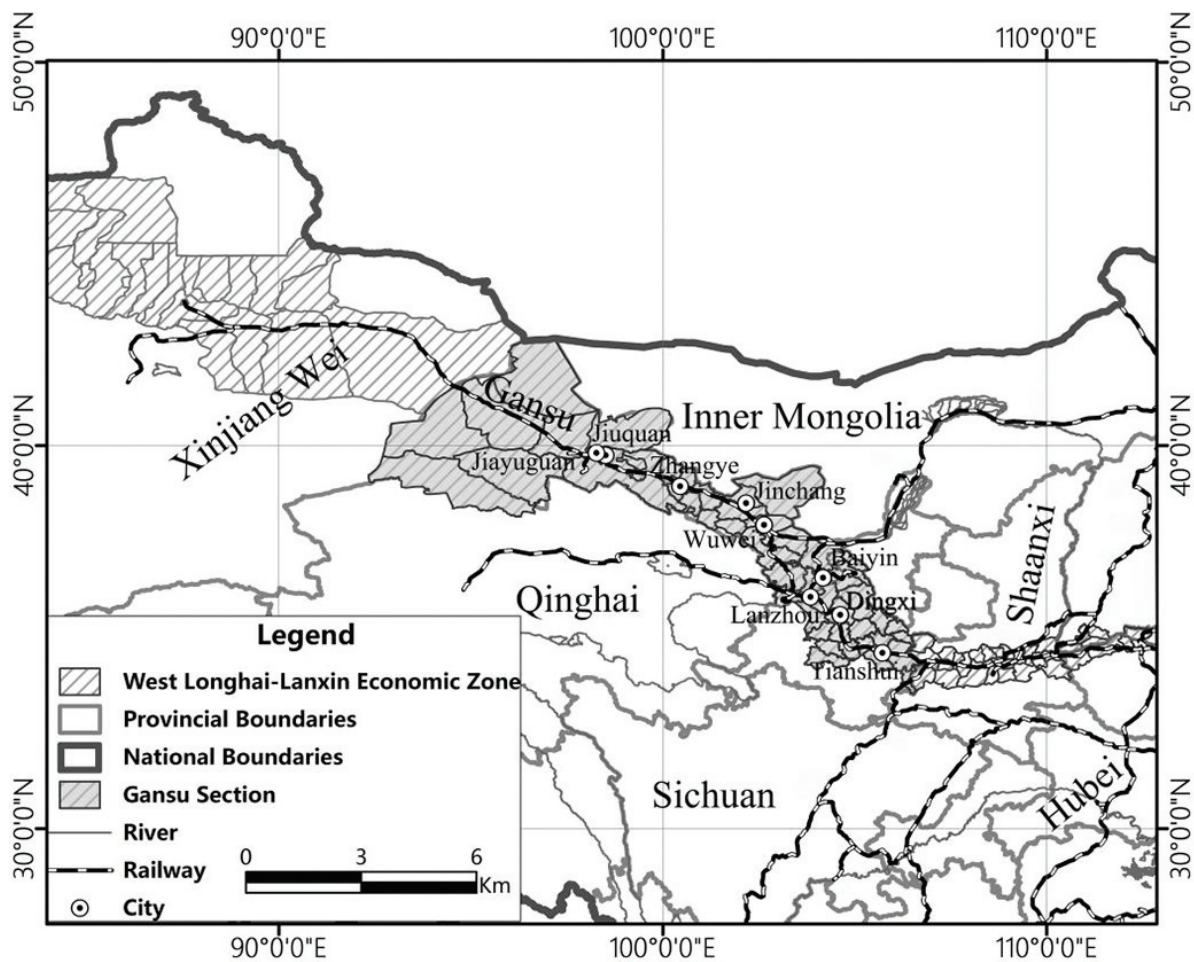
Figure 1. Geographic location map of Gansu section.

3. Materials and methods

3.1. Indicators

The relationship between water resources and urbanization is extremely complex, and no singular indicator can truly reflect the interaction mechanism between the two. Therefore, following available scientific principles and taking into consideration regional dynamics, we first obtained a general set of indicators based on frequency analysis, theoretical analysis and specialist consultation; then, taking into account information overlap, we passed these indicators through correlation coefficient and principal component analysis screening, thereby obtaining final indicators (**Table 1**).

3.2. Data sources and preprocessing

Considering data authoritativeness and availability, the sources of initial data mainly include: precipitation monitoring data from main meteorological stations of Gansu province (1956–2001 Gansu Meteorological Bureau), *Gazette of Water Resources of Gansu Province (1997–2008),*

	Functional groups	Index
Urban system	Population urbanization	Urban population growth rate, proportion of non-agricultural population, population density
	Demographic urbanization	Proportion of non-agricultural industries, per capita GDP, per capita GDP growth rate, economic density of built-up areas, non-agricultural industries density, proportion of industry added value, industry added value per capita
	Social urbanization	Disposable income, per capita spending, per capita road area, Engel coefficient, no. of graduates (m), no. of doctors (m), no. of telephones (m), proportion of science and education funding, per capita living space
	Spatial urbanization	Per capita built-up area, built-up area density, urban density, urban population density
Water resources system	Water resources background conditions	Per capita water resources, resources equivalent runoff, water production module, drinking water quality compliance rate
	Development level of water resources	Per capita water consumption, resource utilization rate, groundwater development and utilization rate
	Efficiency of water resources development	water consumption (10T CNY GDP), gross irrigation water quota, unit food production water consumption, water consumption of industry added value (10T CNY), rate of industrial water usage repetition, citizen water quota, rural residents water quota, proportion of water saving irrigation area
	Water resources management ability	Hydro-science personal (10T), ecosystem water consumption rate (10T CNY GDP), waste water emission amount, urban sewage treatment rate

Table 1. Indicators of water resource and urban systems.

"Statistical Information on Water Resources of Gansu Province" (1956–2001 Gansu Province Hydrology and Water Resources Investigation Bureau), Gazette of Environmental Quality of Gansu Province (2001–2008), Statistical Yearbook of Gansu Province (1990–2008), City Yearbook of Gansu Province (2001–2008), China City Yearbook (1989–2007), statistical yearbooks of each city for many years, plan for national economy and social development of each city, *Study on Water Availability of Main Functional Districts in Gansu Province, Industry Water-use Quota in Gansu Province.* Some additional data belongs to the data accumulated from project undertaken in the past, like the key project of National Natural Science Foundation—The Contemporary Living Environment and Social Foundation Sustainable Development in Hexi Area.

Based on the initial data we selected more than 2000 valued data points between 1989 and 2007, reflecting various aspects of water resource systems and urban systems. Because of the variations in the dimensions of the initial data for the indicators to facilitate horizontal comparison among the nine cities, we used poor standardization methods to treat the data and make it dimensionless:

$$Z_{ij} = \left(X_{ij} - \min_i X_{ij}\right) / \left(\max_i X_{ij} - \min_i X_{ij}\right) \tag{1}$$

where Z_{ij} is the attribute value of a target and $\max_i X_{ij}$, $\min_i X_{ij}$ are the maximum and minimum values of a target.

3.3. Methods

The model for the comprehensive measurement of water resources constraint on urbanization is built upon the integrated indicator system of water resources and urbanization, using the entropy technique of supported analytic hierarchy process (AHP) to calculate the weight of indicators at all levels, using a fuzzy membership function model to calculate the specific membership values of each indicator, the weighted average method to individually calculate the integrated indexes of water resource development potential and the indexes of urban synthesized development, and then using these to calculate the water resources constraints on urbanization, and grade their intensity accordingly [7–9].

(1) Using entropy techniques to correct the weight coefficient determined by the AHP method.

Because there is a complex nonlinear relationship between each factor within the water resources and urban systems, we used the entropy technique of supported AHP to determine the weight of each eligible index.

$$\alpha_j = v_j p_j / \left(\sum_{j=1}^{n} v_j p_j \right), v_j = d_j / \sum_{j=1}^{n} d_j, d_j = 1 - \lambda_j, \lambda_j = -\sum_{j=1}^{n} r_{ij} \ln r_{ij} \tag{2}$$

where a_j is the index weight determined by the entropy technique of supported AHP; p_j is the index weight determined by the AHP; v_j is the index information weight; λ_j is the indicator output entropy power and r_{ij} is the standard matrix after normalization using the AHP determination matrix. Using these equations increased the reliability of the results for each factor.

(2) Using a fuzzy membership model to calculate the membership values of each specific indicator.

In order to solve the problem of differing dimensions for different indicators, with consequent summarization difficulties, it is necessary to eliminate the dimension of each indicator. Considering that there are both positive and negative indicators in the system, the 'good' and 'bad' between indicators are to a large extent fuzzy; hence a fuzzy membership model function method was used to quantify the 'value' of each indicator, treating positive indicators with a higher semi-trapezoid fuzzy membership function, as follows:

$$\Phi_{(e_{ij})} = \frac{e_{ij} - m_{ij}}{M_{ij} - m_{ij}} = \begin{cases} 1 & e_{ij} \geq M_{ij} \\ \dfrac{e_{ij} - m_{ij}}{M_{ij} - m_{ij}} & m_{ij} < e_{ij} < M_{ij} \\ 0 & e_{ij} \leq m_{ij} \end{cases} \tag{3}$$

Treating negative indicators with lower semi-trapezoid fuzzy membership functions results in the following:

$$\Phi_{(e_{ij})} = \frac{M_{ij} - e_{ij}}{M_{ij} - m_{ij}} = \begin{cases} 1 & e_{ij} \geq M_{ij} \\ \dfrac{M_{ij} - e_{ij}}{M_{ij} - m_{ij}} & m_{ij} < e_{ij} < M_{ij} \\ 0 & e_{ij} \leq M_{ij} \end{cases} \tag{4}$$

where e_{ij} is the specific attribute value of the evaluated indicator; i is the number of regions; j is the number of indicators in i region; M_{ij}, m_{ij} are, respectively, the maximum and minimum theoretical attribute values of j indicator in i region and $\Phi_{(eij)}$ is the membership level of j indicator in i region with a value between 0 and 1.

(3) Determining the integrated index potential of water resources development and the index of urban synthesized development.

With the entropy of the weight coefficient and membership values of each indicator, we can use the weighted average to individually calculate the regional integrated index potential of water resources development and the index of urban synthesized development as follows:

$$F_i = \sum_{j=1}^{m} \omega_j \times \Phi_{(e_{ij})} \tag{5}$$

where F_i is the integrated index potential of water resources development or the index of urban synthesized development of i region; ω_j is the entropy weight coefficient of j indicator relative to the highest level target; m is the number of specific indicators in the index system.

(4) Determining the water resources constraint intensity.

The correlation coefficient from the fitted equation between urbanization and total water usage will be an important basis for the measurement of water resources constraint; the smaller the correlation coefficient, the stronger the water constraint, and vice versa.

In the linear regression equation correlation coefficient, R represents the degree of coefficient between the variables X and Y. Generally, R ∈ [0, 0.4] denotes a weak correlation; R ∈ [0.4, 0.6] a relatively strong correlation; R ∈ [0.6, 0.8] a strong correlation and R ∈ [0.8, 1] an extremely strong correlation. The size of R^2, the deterministic coefficient of the regression equation, represents the degree of regression straight line fit, and $1 - R^2$ represents the deviation of the observation and fitting curve.

When the intensity of water resources constraint is 0, urbanization has a logarithmic growth curve in relation to total water consumption; with the increasing intensity of water resources constraint, urbanization increases in a less logarithmic manner in relation to total water consumption; in other words, it becomes increasingly difficult to estimate the urbanization from the logarithmic relationship to total water consumption. Therefore the percentage that cannot be estimated, $1 - R^2$, can be used as an individual measure index of the water resources constraint intensity (WRCI). This method is developed from the statistical analysis of the long-term logarithmic growth of total water consumption in relation to urbanization. If the time

series is not long enough, or if the selected time period is one where the water resources usage is at low growth, zero growth or negative growth, then this model is not suitable.

In order to simplify the water resources constraint intensity (WRCI), so that it resembles the relative degree of water resources constraint on urbanization, two types of integrated indexes are combined to determine the magnitude of water resources constraint on urbanization, for example.

$$WRCI = \alpha \times (1 - F_w) + \beta \times (1 - F_u) \qquad (6)$$

where F_w is the integrated index potential of water resources development; F_u is the index of urban synthesized development and α, β are the systematic influence sharing coefficients ($\alpha + \beta = 1$).

According to the fundamental principles of AHP, as far as the arid regions of northwest China are concerned, their water resources systems can be considered 'very important' to their urban systems (importance level 7), such that $\alpha = 0.875$, $\beta = 0.125$.

Based on the synthesized measurement model for water resources constraint on urbanization, the WRCI can be graded as a weak constraint WRCI ∈ [0.0, 0.3), a relatively strong constraint WRCI ∈ [0.3, 0.5), an intense constraint WRCI ∈ [0.5 0.7) or an extreme constraint WRCI ∈ [0.7, 1.0). Further, each type of WRCI can be classified as one of three grades, such as high, medium or low, for example, intensive constraint-high, intensive constraint-medium and intensive constraint-low.

4. Results and discussion

4.1. Evaluation on water resources system in Gansu section

Evaluate the water resources system in Gansu section, respectively, from the aspects of water resources series elements (rainfall, surface runoff, groundwater, total volume of water resources and water quality), water resources endowment (water production coefficient, water production modulus, agricultural water resources and per capita water resource) comparison among cities, the development and utilization of water resources (water utilization structure, water utilization profit) dynamic changes and so on [10].

4.1.1. Rainfall

Adopt trend analysis method according to the monitoring data from 75 effective meteorological stations (1956–2007), and transfer those station data into the three-dimensional perspective diagram taking property value as height, then project those points to the orthogonal surface with the map surface in two directions, fit each direction by a polynomial, and analyze the overall trend of data set. The overall rainfall in Gansu section shows the decline trend from east to west and from south to north, and the rainfall reduction between south and north is more than that between east and west.

The minimum of actual measured rainfall occurred in Xihu Station of Jiuquan City in 2007 at 3.6 mm. The average rainfall remains 130.4 mm in Inland River Basin for many years, and the total rainfall is 35,214.7 million m^3, which have occupied 28.0% of the multi-year average total rainfall in the whole province; and the average rainfall remains 463.0 mm in Yellow River Basin for many years, and the total rainfall is 67,549.5 million m^3, which have occupied 53.7% of the multi-year average total rainfall in the whole province. The specific conditions of rainfall in each Basin are shown in **Table 2**.

The rainfall in each city is compared with multi-year average. Cities with an increase range over 20% include Jiuquan City, Jiayuguan City, Zhangye City, Jingchang City, Wuwei City, Lanzhou City and Baiyin City, while the increase under 10% include Dingxi City and Tianshui City.

4.1.2. Surface runoff

The water resources in Gansu section mainly and, respectively, belong to two basins of the Yellow River and Inland River. There are five water systems such as Tao River, Huang River, the main stream of Yellow River, Wei River and Jing River in the Yellow River basin; while there are three water systems such as Shiyang River, Heihe River and Shule River (including the water system of Sugan lake) in Inland River Basin. There are 36 tributaries in Yellow River Basin except for the main stream crossing through the middle part of the Province. The Basin is with large-area drainage and advantageous hydraulic conditions and 31 rivers have an annual runoff of greater than 100 million m^3. Most areas within the Basin are covered by loess, with sparse vegetation, serious water and soil loss and high sediment concentration in the river. The Inland River Basin includes three water systems like Shiyang River, Heihe River and Shule River, the basin area is 270,000 m^2. Most river sources originate from Qilian Mountain, and the northward flow and westward flow empty into the Inland Lake or disappear in desert or Gobi. Featured with short flow path, large water volume and strong current in upstream, and shallow river valley, small water volume and diverse riverbed in downstream, but the water volume is stable and the hydro power resources are abundant (**Figure 2**).

Basin	Precipitation		Multi-year average rainfall (100 million m^3)	Comparison with last year ($\pm$%)	Comparison with multi-year average ($\pm$%)	Frequency (%)
	mm	100 million m^3				
Shule River	119.0	202.28	163.189	64.6	24.0	
Heihe River	247.4	146.84	102.298	53.1	43.5	
Shiyang River	279.0	113.52	86.66	24.1	31.0	
Inland River	171.3	462.64	352.147	49.1	31.4	6.0
Yellow River	501.1	731.132	675.495	16.9	8.2	28.9
Total	310.6	1411.466	1258.306	24.9	12.2	11.8

Table 2. The rainfall conditions of each basin in Gansu section (2007).

In 2007, the natural water volume in Inland River Basin is 70.68 billion m³, the converted runoff depth is 26.2 mm, up by 24.8% compared with multi-year average self-produced water volume. Compared with the multi-year average value, the natural water volume in Shule River increases by 26.5%, Heihe River increases by 25.2% and Shiyang River increases by 22.0%. The self-produced water volume of the Yellow River Basin is 110.87 billion m³, and the converted runoff depth is 76.0 mm, down by 11.4% compared with multi-year average self-produced water volume. Compared with the multi-year average, the largest increase is above the Xiangtang Station of Datong River, with an increase of 57.8%. The largest reduction is above Zhangjiachuan of Jing River, with a decrease of 43.1%.

Self-produced water resources in the cities of Gansu section are compared with the average amount of years, the five cities in Hexi corridor have increased by 18–39%. The self-produced water resources of Lanzhou City, Baiyin City, Dingxi City and Tianshui City have decreased in different degrees, ranging from 20 to 40%.

4.1.3. Groundwater

The amount of groundwater resources in the Inland River Basin is 5.9706 billion m³ (2.3667 billion m³ in the mountainous area, 5.3314 billion m³ in the plain area and 1.7275 billion m³ is repeatedly calculated), which is 47.2% higher than the multi-year average of 4.057 billion m³. Pure groundwater resources is 577.6 million m³, increasing by 23.6% compared with the multi-year average of 467.5 million m³.
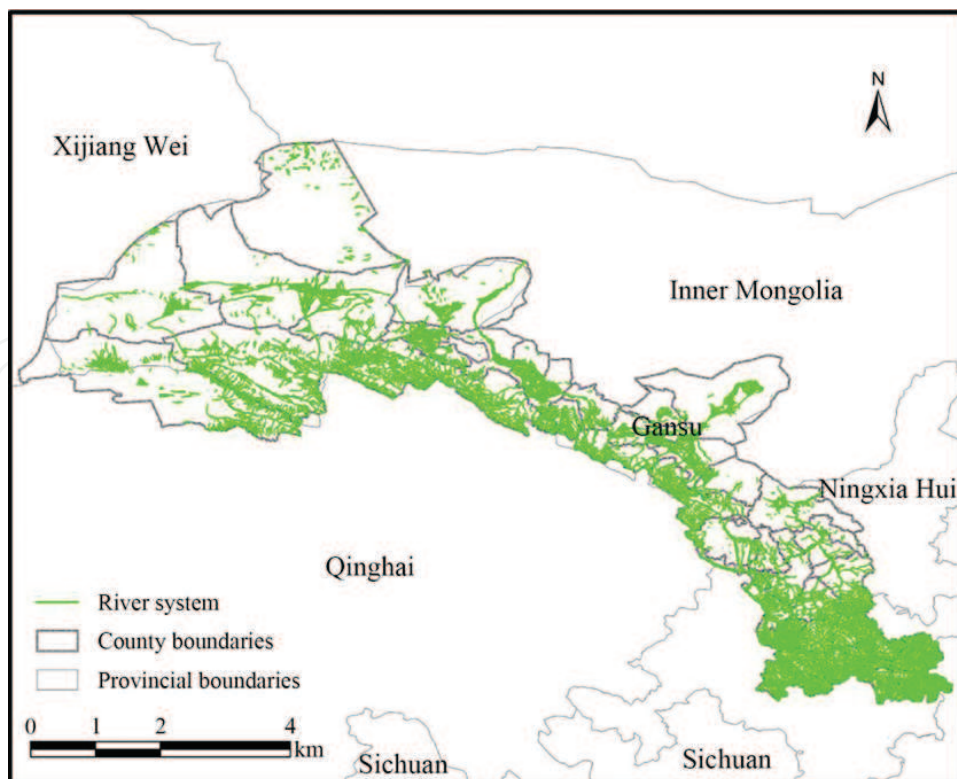

Figure 2. The spacial pattern of surface runoff in Gansu section.

The amount of groundwater resources in the Yellow River Basin is 4.5299 billion m^3 (4.4593 billion m^3 in mountainous areas, 109.8 million m^3 in plain areas and the repeatedly calculated is 39.2 million m^3), which is 0.3% higher than the multi-year average of 4.518 billion m^3. Pure groundwater resources is 387.9 million m^3, increasing by 47.7% compared with the multi-year average of 262.7 million m^3.

4.1.4. Total water resources

In 2007, the surface water resources in the Inland River Basin of Gansu was 7.068 billion m^3, the groundwater resources was 5.9706 billion m^3, the repeatedly calculated amount of the surface water and groundwater was 5.393 billion m^3 and the total amount of water resources was 7.6456 billion m^3, which was 24.7% higher than the multi-year average of 6.1291 billion m^3. Basin water production coefficient is 0.17 and water production modulus is 28,300 m^3/km^2.

The amount of surface water resources in the Yellow River Basin is 11.087 billion m^3, the amount of groundwater resources is 4.5299 billion m^3, the repeatedly calculated amount of the surface water and groundwater is 4.142 billion m^3, and the total amount of water resources is 11.4749 billion m^3, which is 22.6% higher than the multi-year average of 10.0364 billion m^3. Basin water production coefficient is 0.36, water production modulus is 201,900 m^3/km^2.

Affected by both climate change and regional development on the use of water resources, the annual runoff of the basins is generally showing a downward trend, and some basins decreased significantly, indicating that during the process of urbanization, the conflict between urban water supply and demand will become more and more prominent, and the pressure of water resources will be mounting.

4.1.5. Water quality

In 2007, 68.1% of the cross sections of rivers in Gansu section reached the water quality standard. The water in Shiyou River of Yumen City; Shandan River of Zhangye City was increasingly polluted. The water quality of Lanzhou section in the Yellow River was Category III; and in the Baiyin section, the chemical oxygen demand and ammonia nitrogen concentration in three cross sections had been slightly decreased compared with last year, and the water quality was raised from Category III to Category II. In Tianshui section of the Weihe River, the chemical oxygen demand and ammonia nitrogen concentration had been decreased in other three cross sections excepted the Hualin cross section with the water quality being improved compared with last year. The comprehensive indexes for pollution in each cross section in Zhangye section of the Heihe River remained the level last year with excellent water quality. The concentration in such indexes as permanganate index, chemical oxygen demand, biochemical oxygen demand, ammonia nitrogen, and total phosphorus in Shiyang River had been decreased. However, the total water quality pollution in the reach was relatively serious remaining the Category Bad V. The biochemical oxygen demand concentration in Hongyashan Reservoir was increased with the water quality pollution being slightly aggravated.

In the water quality of drinking water source, the water quality of the centralized drinking water sources in nine cities was excellent totally. Except the fecal coliform which exceeded the

standard in January, June, August and September in Baiyin City, the drinking water quality in each monitoring month in other eight cities had reached the standard. Through protecting the drinking water sources and gradually reducing the influence of human activities on the water sources, the water environment situations of the drinking water sources in each city have been improved recently to some extent.

4.1.6. Comparison for water resource endowment of cities

Influenced by multiple factors, the imbalance for spatial distribution of regional water resource had been studied, which had caused the obvious endowment difference in water resources in nine prefecture-level cities (**Table 3**).

The shortage of water resource was relative to the water resource demands in the region. In view of the total water source quantity hardly reflecting the abundance and shortage of water resource in a region, it might be considered to compare such factors as population, agricultural acreage and effective irrigation area and the water resource endowment in the city.

In nine cities, due to limited water resource in Dingxi City and many cultivated lands, the agricultural allocated water resource quantity was the lowest (only 484.24 m³/mu). Due to limited cultivated land resource in Jiayuguan City, the agricultural allocated water resource quantity was the highest reaching 1246.93 m³/mu. The difference exceeded 2.5 times that the discrepancy in water resource conditions of agricultural development in the research region was obvious. In addition, respectively, compared with the whole Gansu Province (11,240.2 m³/mu), the western Longhai-Lanxin economic zone (10,094.0 m³/mu) and the whole country (12,386.4 m³/mu), the total agricultural water condition in the research region was poor (**Figure 3**).

The difference in water resource quantity per capita in nine cities was very large. Lanzhou City has less water and large population size resulting in the low water resource per capita, while

City	Annual rainfall (mm)	Surface water (100 million m³)	Underground water (100 million m³)	Repeated calculation amount	Total amount of water resource	Proportion (%)	Runoff coefficient	Runoff odulus (10,000 m³/ km³)
Lanzhou	55.396	1.491	1.035	0.359	2.167	0.80	0.04	1.60
Baiyin	68.067	1.122	1.627	0.242	2.507	0.93	0.04	1.25
Tianshui	83.140	13.240	5.571	5.237	13.574	5.05	0.16	9.48
Dingxi	96.530	8.344	3.980	3.484	8.840	3.29	0.09	4.51
Wuwei	89.252	13.430	10.039	8.331	15.138	5.63	0.17	4.55
Zhangye	138.93	36.749	26.416	24.491	38.674	14.38	0.28	9.45
Jianchang	20.785	0.614	2.244	1.969	0.899	0.33	0.04	1.18
Jiuquan	229.47	26.048	22.799	21.049	27.778	10.33	0.12	1.45
Jiayuguan	2.167	0.013	0.430	0.360	0.083	0.03	0.4	0.64

Table 3. Comparison for water resources in various cities of Gansu section (2007).

Jiayuguan was extremely short of water resulting in the worst situation per capita. Similarly, compared with the whole Gansu Province (1150 m³/person), the western Longhai-Lanxin economic zone (1660 m³/person) and the whole country (2400 m³/person), for the water resource per capita in nine cities, only two cities had better situations and the rest was poor (**Figure 4**).
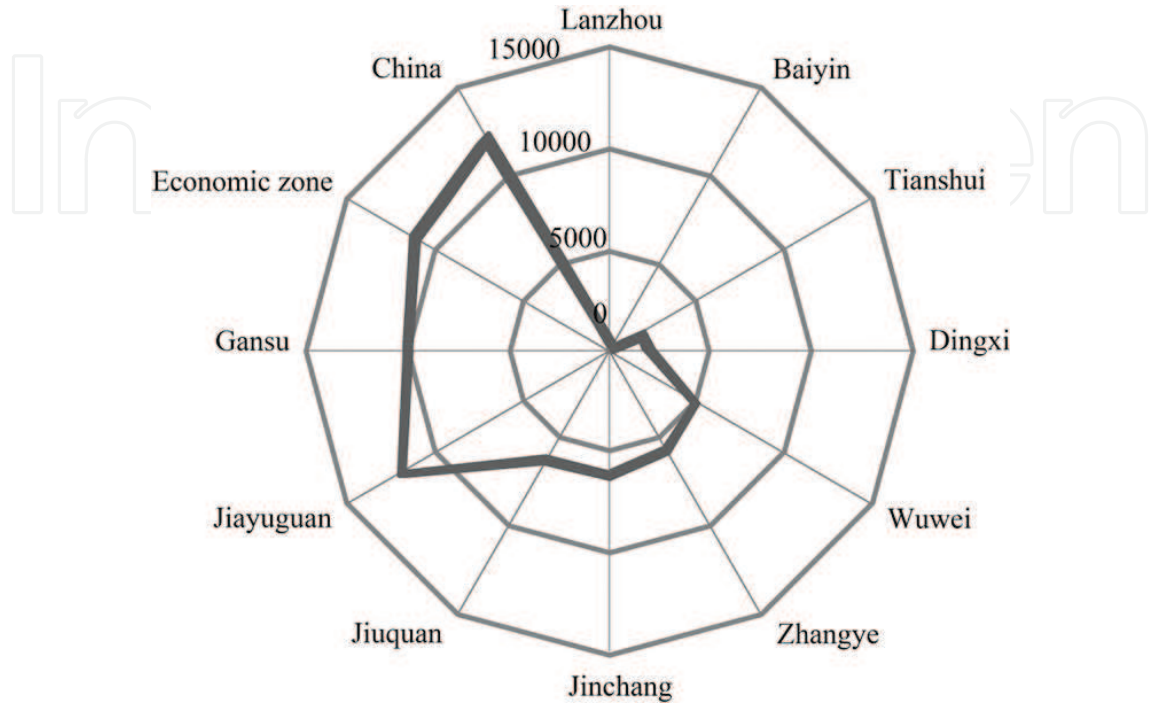

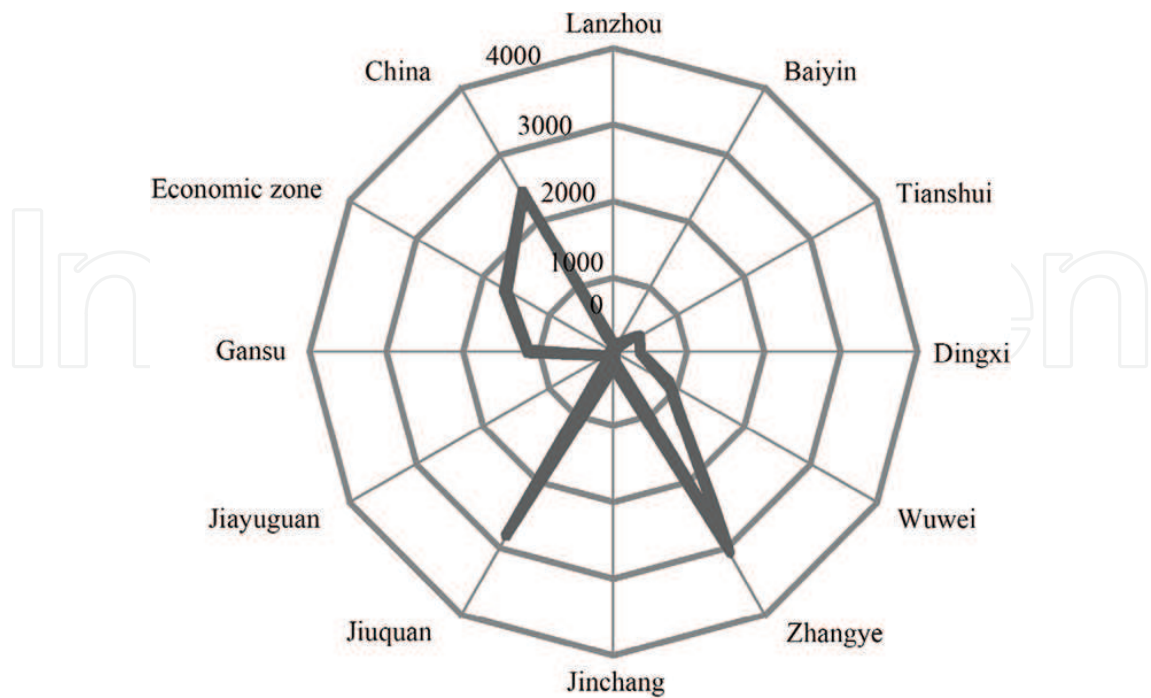**Figure 3.** The agricultural allocated water resources.

Figure 4. The water resources per capita.

4.1.7. Water resource development and utilization

The ways to use the water resource generally contained three aspects, namely agricultural water, industrial water together with public water in cities and domestic water of residents. Due to different development scales, development degrees and water demands among nine cities in Gansu section, corresponding difference in the water resource consumption was obvious. Besides, the changes for three types of water utilization in several key phases were very large with all types of water utilization presenting the increase trend as a whole. In the water utilization structure, except more industrial water used in Lanzhou City and Jiayuguan City almost accounting for a half, other cities mainly utilized the water in agriculture, especially in Wuwei, Zhangye and Jiuquan located in the Inland River Basin, the proportion of agricultural water exceeded 90%, which were the typical agricultural development-oriented regions. Besides, there were large differences in the water transfer directions and ranges in each city related to the specific situations of industrial development in each city.

The water resource efficiency is an important index reflecting the development and utilization of water resource and an index reflecting the development and utilization potential of water resource in a region. Two indexes, namely agricultural water consumption per 10,000 yuan output value and industrial water consumption per 10,000 yuan output value were adopted here to compare the water resource utilization efficiency in each city in Gansu section for many years.

As a whole, the agricultural and industrial water utilization efficiency in most cities were increasing with large increased range in the industrial water utilization efficiency. There were abnormalities in some cities: in Lanzhou City and Jinchang City, the agricultural water consumption per 10,000 yuan output value was lower in other years than that in 1991 relating to small irrigation area at that time; and in Wuwei City, the lower industrial water consumption per 10,000 yuan output value in 1991 was caused by seriously insufficient industrial development at that time with relatively less water consumption.

In 2007, the agricultural and industrial water consumption per 10,000 yuan output value in Gansu Province were 3414.01 m^3 and 104.07 m^3, respectively. Accordingly, in western Longhai-Lanxin economic zone, the corresponding values were, respectively, 5322.45 m^3 and 141.62 m^3; and in the whole country, the values were, respectively, 1301.25 m^3 and 121.48 m^3. Compared with them, the situations in each city in Gansu section were good or bad (**Figure 5**) reflecting the obvious relative difference in water-saving level and efficiency among them.

4.1.8. Comprehensive judgment for abundance degree of available water resources

The abundance degree of available water resource quantity was comprehensively judged from such information as spatial and temporal distribution and development and utilization degree of water resource and water composition in 42 counties in Gansu section. In order to more directly show different abundance degree among counties, **Figure 6** could be applied for analysis that in 42 counties in Gansu section, 25 of them had the situations in and below the medium almost accounting for 60% reflecting relatively insufficient water resource in most of regions with poor water utilization conditions. In addition, the counties with more available water resource quantity were mainly located at the south of Gansu section in space, while the
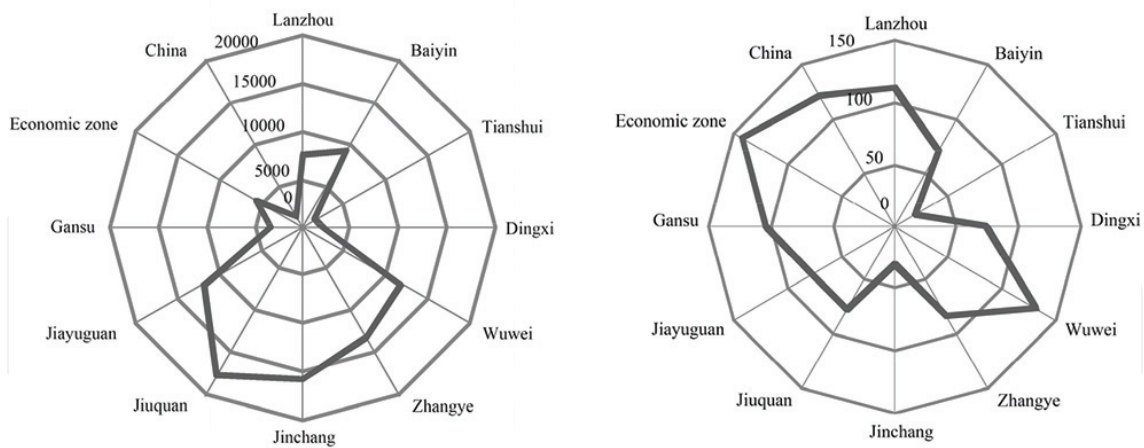
Figure 5. Comparison for water consumption per 10,000 yuan output value (left: agriculture; right: industry).
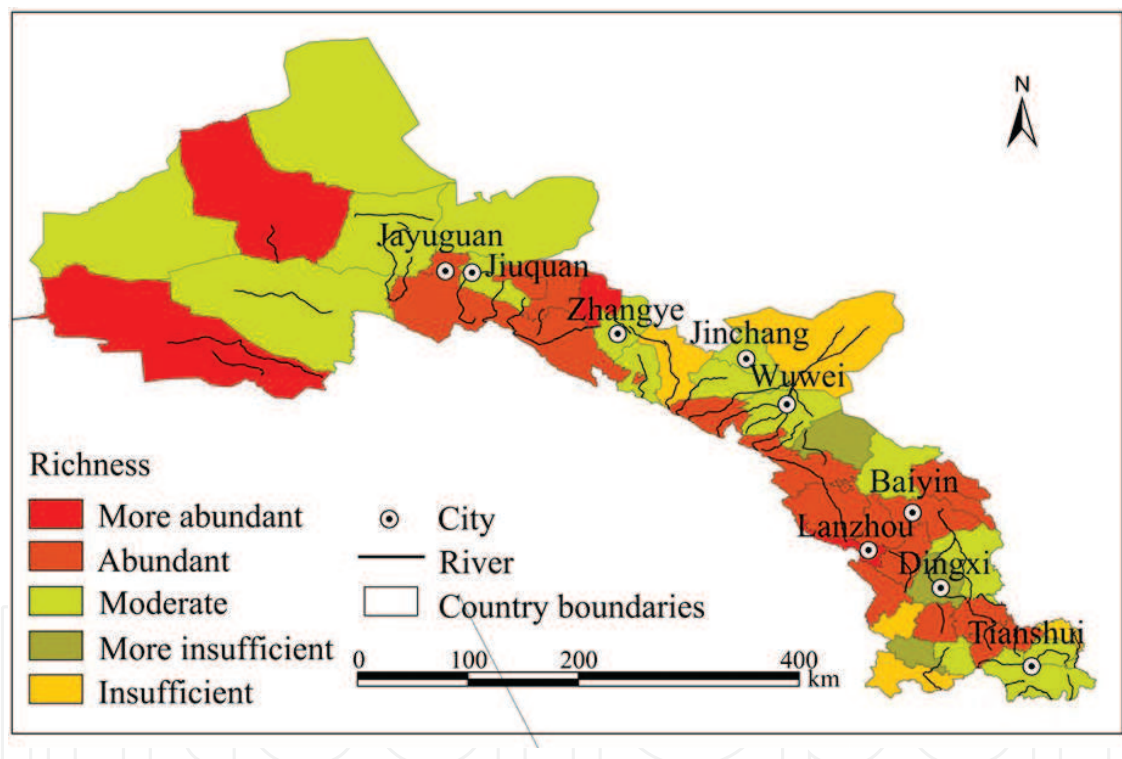

Figure 6. Comprehensive judgment for richness of available water resources in 42 counties of Gansu section.

economic center of Gansu section was mainly centered on the middle part along the axial zone of Lanzhou-Lianyungang Railway. Therefore, the water resource and economic development in Gansu section were poorly matched spatially.

4.2. Evaluation on urbanization system

The urbanization had diversified meanings, mainly including four aspects, namely population urbanization, economic urbanization, social urbanization, and spatial urbanization. The population urbanization was the foundation. The population urbanization referred to the dynamic

process of rural population being converted and centered to the city and the proportion of urban population being gradually improved, mainly including three ways, namely natural increase in urban population; a batch of rural population pouring into the city and rural population locally converted into the population in urban life style through the social and economic development. Due to different types of society, economy, culture and ecology in all cities, the progress, characteristics, ways and social consequences of population urbanization were definitely and largely different [11].

4.2.1. Dynamic changes in population urbanization development in all cities

Due to diversified historical relics, local and natural resource conditions, economic and social development basis and investment environment in all cities, differences existed in the urbanization in each city. Compared each other in several selected years, the differences in the population urbanization could be seen (**Figure 7**).

Several cities with higher urban level and faster increased range were successively: Jiayuguan, Lanzhou and Jiuquan, and other six cities were approximately same without large difference reflecting the relatively stable boost of population urbanization in Gansu section as a whole with few prominent regions.

4.2.2. Dynamic changes in population urbanization development in all counties

In different periods, the difference of the population urbanization progress in counties was relatively obvious with rich contents. After respective comparison of urbanization level in each county in 1995 and the average growth rate of urbanization in previous 5 years with those in 2007 accordingly, the changes and differences in the development trend for urbanization progress could be judged (**Figure 8**).

The urbanization level in most of counties in Gansu section was lower than the average level in 1995. There were only 15 counties higher than the average level indicating the obvious
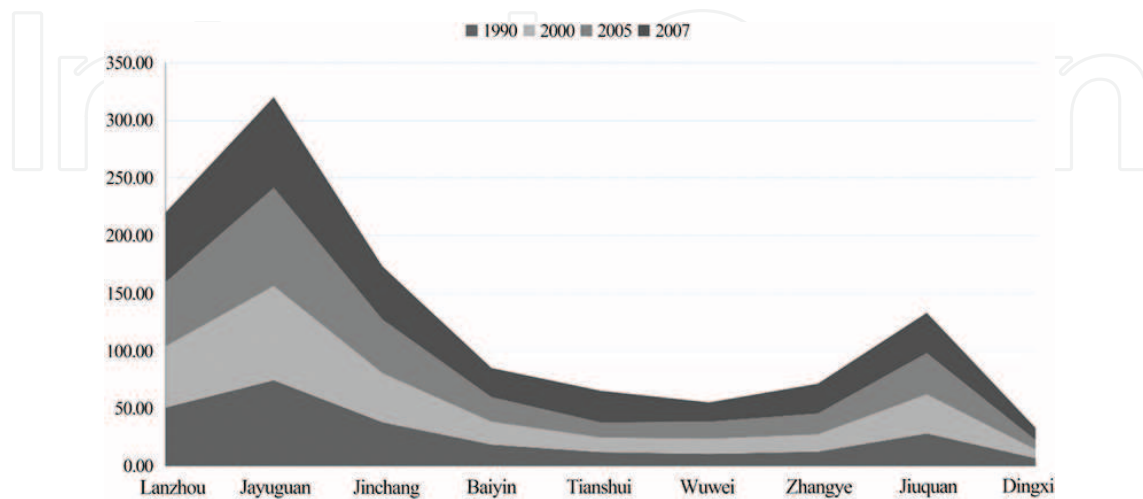

Figure 7. Cumulative curve for population urbanization expansion in nine cities in Gansu section.
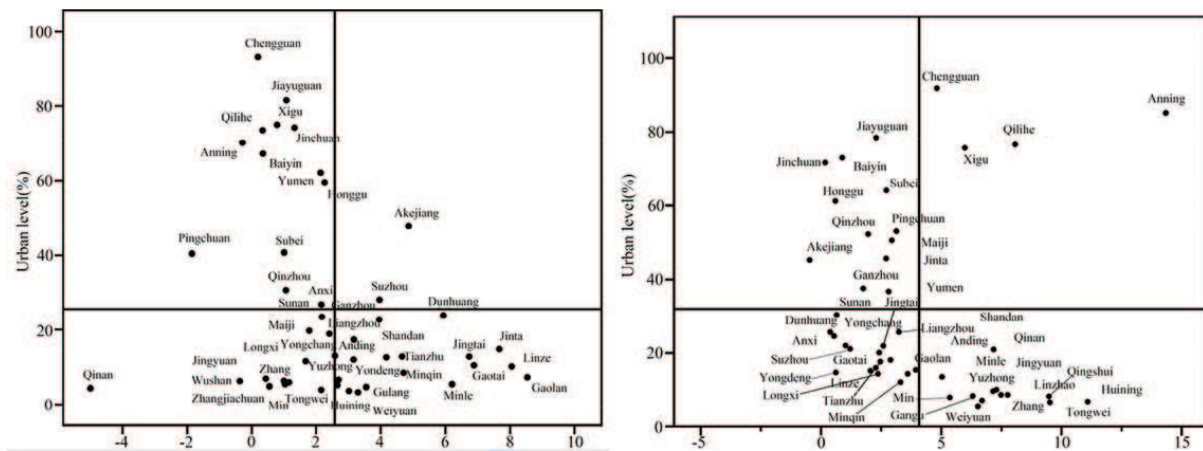
Figure 8. Difference of level and average growth rate of population urbanization in 42 counties.

polarization; and there were many counties with the growth speed higher than the average level reflecting good development trend as a whole with certain potential growing group existed. Only Kazak Autonomous County of Aksay and Suzhou District had high level and high growth speed with less influence. Until 2007, the urban level and urban growth of all counties and districts were distributed dispersedly reflecting the shrinkage of group difference; and the number of counties or districts having higher level and higher growth speed were increased to four, which were the areas under administration of Lanzhou city, the capital city, reflecting strong centralization of the central city.

4.2.3. Comparison of population urbanization

Place the population urbanization of Gansu section, respectively, in different background (Gansu Province, the economic zone, the Northwest China, the western China and China) for comparison, to judge its process speed and determine the opportunities and challenges it was faced with (**Figure 9**).
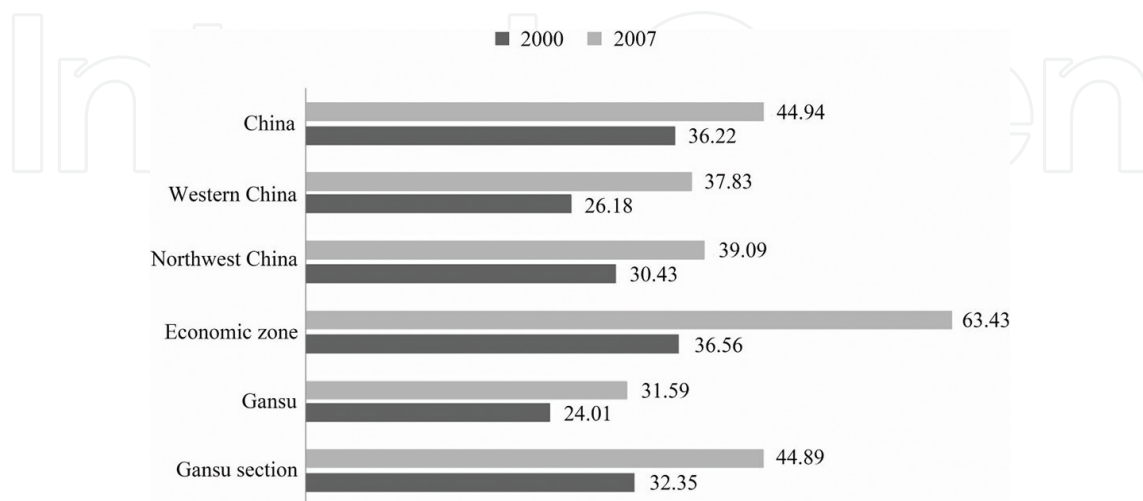

Figure 9. Comparison of population urbanization.

As s a prior-developed area in the northwest China, the urbanization level of Gansu section in 2007 (44.89%) was obviously higher than the level of the whole province in the synchronized period (31.59%), and it was also higher than the average levels in Northwest China and western China (39.09%, 37.83%), it was very close to the national average level (44.94%), but it was still lower than the level of western Longhai-Lanxin economic zone (63.43%), which reflected the developing depression situation of the Gansu section as economic zone was continuously existing. From 2000 to 2007, the urbanization level of Gansu section has increased by 1.79 point each year, and it was, respectively, higher than that of the whole province (1.08), the Northwest China (1.24), the western China (1.66) and the National (1.25), which reflected the Gansu section belongs to the area with good developing environment compared with large-area background, but its increasing speed of urbanization rate was lower than that of the economic zone (3.84), which also reflected that the competition situation of Gansu section in the whole economic zone was relatively poor and the development was relatively slow. For the Gansu section, which promotes economic recovery by urbanization, the high-speed development for the urbanization is essential in the future and the restraints of resource like water resources arising from it will be increasingly prominent.

4.3. Temporal-spatial variation of water resource restraints

4.3.1. Results and analysis of F_w and F_u

Based on the above formula (5), we can calculate the synthesized index potential for water resources development F_w for the Gansu section and for each city within it. In view of the physical significance of F_w, a value of 1 for F_w indicates that the water resource system was broadly undeveloped, and that all the water resources were left for the eco-environmental system; a value of 0 for F_w indicates that 100% of the water resources were developed and used for the socioeconomic system, and no water resources were left for the eco-environmental system. F_w shows a positive development, particularly since 2002, in the Gansu section, reflecting that after years of efforts such as water conservation and appropriate allocation, etc., the socio-economic system started returning water to the eco-environmental system, resulting in nearly 30% (the average value of F_w was 0.2972) of water resources being left for the eco-environmental system. There are, however, F_w differences among the nine cities. Both Lanzhou and Jiuquan had relatively smaller F_w values for different reasons. Lanzhou city's value is the result of environmentally friendly urban development, whereas Jiuquan city's value was caused by a low level of water development. The remaining seven cities had relatively equivalent and larger values of F_w. Wuwei city, one of the Inland River (Shiyang River) cities, has been increasing its proportion of water left for the eco-environmental system through large national and local efforts on the reasonable use of water. But compared to the international alert level of 40% water resources development (i.e., 60% of water remains for the ecosystem), all nine cities of the Gansu section should return more water from the socioeconomic system to the ecosystem [7].

Similarly we can calculate the synthesized index of urban development F_u for the Gansu section and for each city within it. There has been a continuous increase of F_u in the Gansu section and in each city within it for the last 20 years. The F_u of the Gansu section has risen from slightly more than 0.3 in 1989 to nearly 0.5 in 2007, an average annual increase of more than 0.01, reflecting rapid urban development in the Gansu section. Among the nine cities, the

F_u of four cities: Lanzhou, Jiayuguan, Jingchang and Tianshui: is relatively larger than that of the other five cities: Jiuquan, Zhangye,Wuwei, Baiyin and Dingxi, reflecting unbalanced urban development in the Gansu section.

Furthermore, comparison between F_w and F_u shows development changes and coupling trends over time. In general, in the last 20 years, after various efforts, there have been sustained increases in the level of Gansu section's urban development, and a gradual drop in the development level of water resources (moderate increases of corresponding F_w). Especially in the twenty-first century, less than 70% of the water resources have been developed, although this level is still much higher than the international alert level of 40%. At the same time it can be seen that the rise in the Gansu section's F_w is clearly smaller than that of its F_u, so that the relative constraint of water resources on urbanization has not declined, and water resources management will become increasingly difficult if this trend is not reversed [7].

4.3.2. Comprehensive measurement of water resources constraint on urbanization

Using formula (6) we can determine the individual intensities of water resources constraint on urbanization for the Gansu section and its nine cities (**Table 4**).

Year	Lanzhou	Jiayuguan	Jinchang	Baiyin	Tianshui	Wuwei	Zhangye	Jiuquan	Dingxi	Gansu section
1989	0.6463	0.7095	0.7122	0.7628	0.6616	0.7876	0.7961	0.7840	0.7174	0.7309
1990	0.6408	0.7219	0.7229	0.7792	0.7148	0.7975	0.8078	0.7193	0.7342	0.7376
1991	0.6334	0.7235	0.7033	0.7608	0.6709	0.7806	0.7926	0.7266	0.7167	0.7231
1992	0.6260	0.6811	0.7076	0.7586	0.6668	0.7445	0.7700	0.6940	0.7299	0.7087
1993	0.6178	0.7312	0.6975	0.7521	0.6887	0.7593	0.7618	0.6915	0.7091	0.7121
1994	0.6107	0.7186	0.6947	0.7481	0.7076	0.7621	0.7710	0.7259	0.7453	0.7204
1995	0.6023	0.7154	0.6982	0.7472	0.7227	0.7619	0.7661	0.6943	0.7424	0.7167
1996	0.5948	0.7094	0.6996	0.7493	0.7232	0.7528	0.7568	0.7021	0.7484	0.7151
1997	0.5855	0.7114	0.6918	0.7441	0.6954	0.7402	0.7475	0.7171	0.7395	0.7080
1998	0.5886	0.7177	0.6885	0.7402	0.6978	0.7457	0.7440	0.6690	0.7401	0.7035
1999	0.5896	0.7141	0.6998	0.7513	0.6889	0.7363	0.7557	0.6755	0.7321	0.7048
2000	0.5855	0.6975	0.6834	0.7527	0.6686	0.7281	0.7393	0.6664	0.7296	0.6946
2001	0.5822	0.7073	0.6836	0.7457	0.6990	0.7149	0.7375	0.6429	0.7416	0.6949
2002	0.5723	0.6278	0.6905	0.7385	0.6084	0.6846	0.7262	0.6722	0.6909	0.6679
2003	0.5980	0.5829	0.6940	0.7484	0.6835	0.6565	0.7280	0.6813	0.7264	0.6777
2004	0.5040	0.6810	0.6652	0.7509	0.6155	0.6408	0.6895	0.6274	0.6969	0.6523
2005	0.5220	0.6733	0.6207	0.7353	0.6454	0.6566	0.7097	0.6504	0.7130	0.6585
2006	0.4919	0.6696	0.6169	0.7193	0.6204	0.6457	0.6963	0.6144	0.7029	0.6419
2007	0.4789	0.6795	0.6121	0.7231	0.6469	0.6674	0.7034	0.6344	0.6967	0.6492
Average	0.5827	0.6933	0.6833	0.7478	0.6751	0.7244	0.7473	0.6836	0.7238	0.6957

Table 4. Gansu section and individual cities' 1989–2007 annual variations of WRCI.

From 1989 to 2007 the WRCIs both for the Gansu section and for each individual city have been decreasing, albeit with much fluctuation. Since 2000, particularly, most cities had accelerating decreases in WRCI, with Lanzhou and Jingchang being the most obvious, thanks to a rational allocation of water resources, the amount of national and local investments in water-saving techniques and cyclic utilization of waste water, better water resource management and water-saving awareness, etc. There are, however, obvious differences among the WRCIs of the nine cities of the Gansu section, reflecting variations in the WRCIs. Specifically, the situations in these nine cities over this period have been: Lanzhou changed from intensive constraint to relatively strong constraint, with a significant decline in its WRCI; five cities changed from extreme constraint to intensive constraint, including Wuwei and Jiuquan with significant declines in their WRCI, Jiayuguan and Jinchang with no dramatic declines and Dingxi with a fluctuating decline; three cities remained at the same level of water resource constraint, including Zhangye and Baiyin with extreme constraint, and Tianshui with intensive constraint [7].

4.3.3. Spatial differences among types of water resources constraint on urbanization

Based on ArcGIS and the 20-year average of WRCI for each city, the spatial differences among the types of water resources constraint in the nine cities in the Gansu section are shown in **Figure 10**. In particular, Lanzhou, the capital city of Gansu province, belongs to the relatively strong constraint-high type, four cities including Jiuquan, Jiayuguan, Jinchang and Tianshui, belong to the intensive constraint-high type, and the remaining four cities, including Zhangye, Wuwei, Baiyin and Dxingxi, belong to the extreme constraint-low type. These
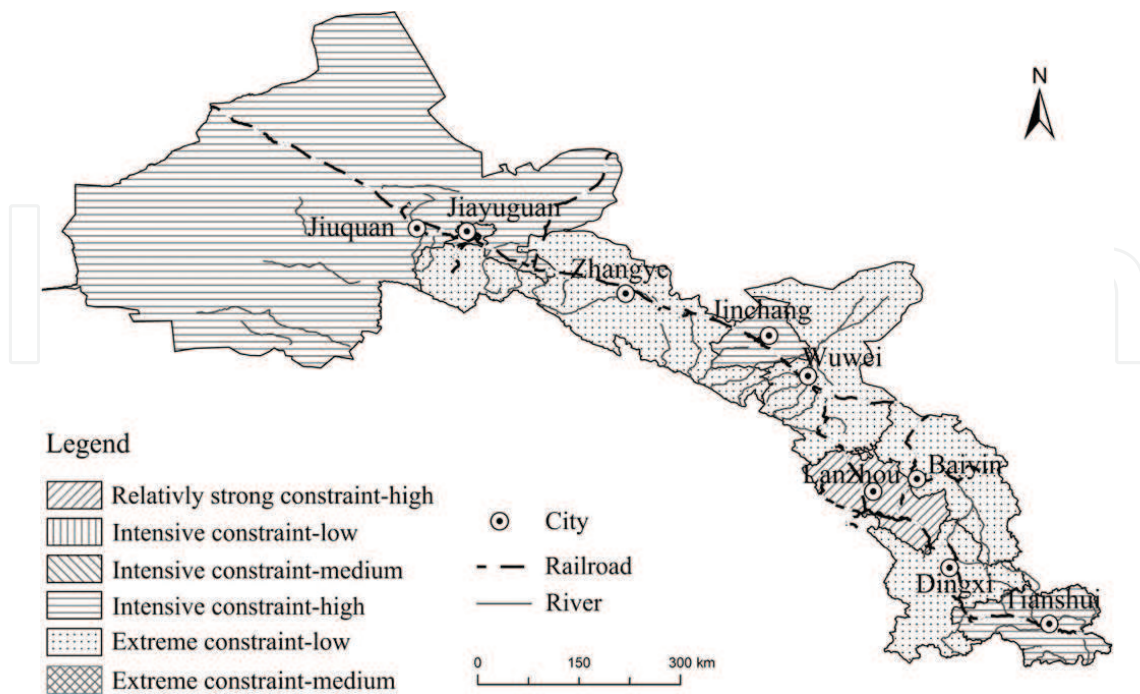

Figure 10. Spatial differences among types of water resource constraints on urbanization in cities.

results show that the Gansu section will continue to be affected by water resources constraint on urbanization and local economic development for some time to come [7].

Improving the urbanization level is the important way to reduce the strength of water resource restraints, but improving urbanization itself will not lead to the increasing strength of water resource restraints, in the certain stage, the reason why the strength of water resource restraints increases with the development of urbanization is that deterioration of water resource health conditions exceeds the improvement of urbanization system health conditions, which eventually lead to the overall deterioration of composite system health conditions.

5. Conclusion

The rainfall and surface runoff, in Gansu Section of western Longhai-Lanxin Economic Zone, showed the pattern of high in east, low in west, abundant in south and few in north, all cities were significant different in water resource endowment; for the water utilization structure, except more water for industrial utilization in Lanzhou City, Jiayuguan City, which has occupied almost half of all, the other cities mainly utilized water for agriculture, especially in the Wuwei, Zhangye and Jiuquan City of the Inland Basin, and all of their proportions of agricultural water utilization were over 90%, and they were the areas which typically oriented by agricultural development. Besides, the transferring directions and transferring amplitude of water utilization in all cities had great difference, which was related to the specific conditions of the industry development of all cities; for the water utilization benefits, although all kinds of benefits were increasing, but compared with the economic zone and the whole nation, it did not own obvious advantages and there was still difference in the internal.

The comprehensive development level of utilization was the highest in Jinchang and lowest in Dingxi, and Lanzhou ranked in the third place, and this was caused by the composition differences of respective utilization connotation. In the aspect of population urbanization of Gansu section, among nine cities, the faster increasing amplitude only existed in Jiayuguan, Lanzhou, Jiuquan and Jinchang, which reflected the whole urbanization promotion was slow and there was less significant areas; the polarization of urbanization for 42 cities was obvious, and the increasing speed higher than the average level was rather more, and this reflected that the whole development conditions were rather good and there was certain increasing potential group. Compared with the Northwest China and the whole nation, the urbanization development in Gansu section owned certain advantages, but compared with the economic zone, both of its urbanization level and increasing speed were rather low, which reflected the developing depression situation of the Gansu section as the economic zone continuously existed.

For all nine cities, the water resource strongly restrained their urbanization, to be specific, Wuwei, Zhangye, Baiyin and Dingxi were extremely strong restrained type, while other cities were strong restrains type, and Lanzhou was relatively the lowest in water resource restraints. From 1989 to 2007, the water resource restraints strength in Gansu section and all cities

fluctuated certainly but the fluctuation was rather small, but since 2000, there was a dropping trend of water resource restraint strength in most cities and it tended to speed up, and it was especially obvious in Lanzhou and Jinchang City. On the multi-year average, excepted that Lanzhou was the strong type of water resource restraints (high) and Tianshui was the strong type of water resource restraints (high), the water resource restraints type of other seven cities was extremely strong (low), and this reflected Gansu section, in its overall socioeconomic development, has born high pressure of water resource, the task to coordinate water resource restraints strength was rather difficult.

Although with the development, the water resource to restrain the urbanization development of most cities has slowed down in a certain extent, in a very long time, the water resource still will be the strong limiting factors for the urbanization development in this area and it needs to be coped with reasonably. The mitigation approach to water restraints includes: build effective, water-saving, pollution-preventing and contemporary agricultural system, effective, water-saving, pollution-preventing industrial and mineral industry, effective, water-saving, pollution-preventing urban-rural system and reasonably allocate water resource.

The relationship between the urbanization and water resource is interacting and cross-coupling. On one hand, the urbanization has stress to water resources through increasing population, economic development, water resource consumption and regional expansion; on the other hand, water resources restrains the development of the city in the way of industry locations, population migration, water resources restraints, and fighting for water resource development fund and policy intervention of water resource development. Water resources system and the urbanization are two aspects of one relationship, in the past, most Chinese scholars placed the emphasis of their research on the stress of cities' development to water resource, and this research, rarely from the view of water resources, kept the idea of water resource restraints throughout the research to quantificationally evaluate the spatial-temporal change of urban process and strength from macro scales (provincial level), and this is not only the beneficial complement for that the research of water resource bearing capacity and water resource pressure is inadequate to cover the interaction between water resource system and socioeconomic system, but also beneficial to expanding the economics research of macro-increasing economics to provide decisive basis to realize the coordination and sustainable development for the water-ecology-society system.

Two large systems: water resource and urbanization built in this research have involved over 2000 data, the data amount is large, the individual data source is inconsistent, and in addition, the availability of individual index and data is poor, so the data for part of the years is obtained by adopting interpolation method and tendency method, and the objectivity is insufficient, all above need to be further improved.

With the promotion of the Silk Road, the Gansu section of western Longhai-Lanxin economic zone will also enter into a new and fast-speed development period, and its water resource pressure and restraining issues during the development will be more prominent. Estimating the future to coordinate the present, and research emphasis in the next step will comprehensively

integrate all kinds of qualitative and quantitative analysis method and simulate the restraint mechanism of water resource in the future to the urbanization and forewarn the sustainable development model in different circumstances of water resources.

Acknowledgements

Author details

Gao Xiang

Address all correspondence to: xgao@lzu.edu.cn

College of Earth and Environmental Sciences, Lanzhou University, Lanzhou City, China

References

[1] Biswas AK. Water for sustainable development in the 21st century: A global perspective. International Journal of Water Resources Development. 1991;**4**:219-224

[2] McMichael AJ, Haines A, Slooff R, Kovats S, editors. Climate Change and Human Heath. Geneva: World Health Organization; 1996. p. 297

[3] Changming L, Xi-wu H. Strategies on Water Problems in 21st Century in China. Beijing: Science Press; 1996. p. 77-81

[4] World Water Council. World Water Vision, London: Earthscan Publications Ltd; 2000. p. 46-70

[5] Wen-lai J. Study on water resources safety strategy for China in the 21st century. Advance in Water Resources. 2001;**12**:66-71

[6] Chuang-lin F, Xiao-lei Z. The development orientation and the industrial division of the node cities along the western long Hai-Lan Xin economic zone. Geographical Research. 2003;**22**:455-464

[7] Gao X, Tengfei Y. The temporal-spatial variation of water resources constraint on urbanization in the northwestern China: Examples from the Gansu section of west Longhai–Lanxin economic zone. Environment and Earth Science. 2014;**71**(9):4029-4037

[8] Bao C, Fang CL. Temporal and spatial variation of water resources constraint on urbanization in arid area. Acta Geographica Sinica. 2008;**163**:1140-1150

[9] Bao C, Fang CL. Scenario warning and analysis of water resources constraint intensity on urbanization in arid area. Journal of Natural Resources. 2009;**9**:1509-1519

[10] Chuang-lin F, Chao B, Biao Q. Urbanization Process and Its Eco-environmental Effects. Beijing: Science Press; 2008. p. 97-124

[11] Chuang-lin F. Urbanization Process of China and Resource-Environment Report. Beijing: Science Press; 2008. p. 35-58